DIAGNOSTICS FOR EMISSION CONTROL SYSTEM MALFUNCTION ON THREE-WAY CATALYST-EQUIPPED VEHICLES

Executive Summary

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S.1 PHASE I: DEVELOPMENT OF GENERALIZED DIAGNOSTIC PROCEDURES

1. INTRODUCTION

Emission standards for model year 1980 and later cars have required many auto-manufacturers to employ sophisticated emission control systems with "three-way" catalysts. Such catalysts require careful control of engine operating parameters to obtain optimum emission control. Many of these emission control systems utilize electronic controls of engine parameters that link the various individual components together to operate as an integrated system. Each manufacturer has developed alternative emission control system designs that, while often similar in concept, are substantially different in design and construction from those developed by other manufacturers. The resulting variety of alternative systems has strained the ability of the service sector to diagnose and repair malfunctions, as they have made traditional trial and error methods of analyzing engine and emission control system malfunctions virtually impossible. To aid mechanics diagnose such systems, manufacturers have developed separate specialized diagnostic equipment and testing procedures, but the equipment varies by individual vehicle type and model year.

Since it appears questionable whether the service industry can rapidly adapt to this changing environment, the California Air Resources Board (CARB) contracted EEA to: (1) review current manufacturer-recommended diagnostic procedures for identifying emission control malfunctions; (2) survey diagnostic techniques used in the field; and (3) develop and recommend a set of standardized diagnostic procedures for use by service industry mechanics. The scope of the effort was restricted to three-way catalyst equipped cars, while diagnosis of malperformance was required for the following emission control sub-systems:

- The EGR system
- The Secondary air system
- The fuel system
- The catalyst

2. REVIEW OF MANUFACTURER RECOMMENDED DIAGNOSTIC PROCEDURES

As a first step towards the development of standardized diagnostic procedures for three-way catalyst equipped cars, a detailed review of manufacturer recommended diagnostic procedures was undertaken. The CARB had established a reference list of 17 vehicles representing the spectrum of emission control technology designs utilized in current vehicles. The survey of manufacturer recommended procedures was based on the methods recommended in their repair manuals for the 17 vehicles specified by the CARB. EEA organized the emission control technologies employed in the reference list of cars into groups that employ similar emission control strategies and reviewed the diagnostics recommended for each group.

The review was limited to diagnostics of malperformance of the four emission control sub-systems. In addition, EEA has reviewed only those parts of the fuel system that are specially designed for emission control in conjunction with three-way catalysts. This is because many of the components of the fuel system relate only to fuel delivery, not to emission control. The study methodology assumed that the procedures for dealing with malfunctions for such components are widely understood as they have been available for many years. Hence, diagnostics and repair methods for malfunctions such as carburetor idle-mixture, sticky choke or binding throttle linkages are not the subjects of this study although any of these malfunctions can induce significant increases in emissions. Since the study of diagnostic methods and repair of these malfunctions would result in essentially duplicating Bureau of Automotive Repair (BAR) developed diagnostics, the study limitations were chosen to maximize our efforts to develop diagnostics for new three-way catalyst related emission control technology.

Surprisingly, the GM Chevette shop manual was the only one of the 17 examined to provide mechanics a listing of possible causes of emissions failures for HC, CO, and NO_x. Other manuals such as the ones for Toyota and Ford vehicles provide some guidance on specific malperformances or warnings on secondary air division, but most manuals provide no guidance whatsoever to mechanics on potential causes for emissions failures. All manuals provide diagnostics for driveability related defects -- e.g., surge, stumble, failure to start, backfire -- which may, in some cases, lead to correction of an emissions related failure.

The review revealed considerable similarities between the different manufacturers' recommended diagnostic procedures for diagnostics of the secondary air and EGR systems, but recommendations for fuel system diagnostics displayed considerable diversity. As a result, the fuel systems were grouped into four technologically distinct categories, namely:

- Open-loop carburetors
- Closed-loop carburetors
- Mechanical fuel injection
- Electronic fuel injection

Manufacturer recommended diagnostics within each fuel system category were similar except for electronic fuel injection systems. Electronic systems were found to require special diagnostic equipment unique to each manufacturer. Little information is provided by the manufacturers on diagnostics for malfunctioning catalyst systems.

3. SURVEY OF FIELD MECHANICS

A survey of field mechanics was conducted in order to understand the procedures currently used by mechanics to repair emission control malfunctions in three-way catalyst cars. The survey also elicited their concerns regarding data availability, usefulness and shortcomings of manufacturers' recommendations and difficulties in implementing available procedures. The purpose of the survey was to obtain some insight into mechanics' diagnostic methods so that generalized diagnostic procedures could be designed to address mechanics' abilities and concerns. The resource limitations of the project made it impossible to conduct a formal, statistically valid survey. Rather, this survey was primarily for informational purposes to aid in the design of diagnostic procedures and the data presented here should be construed as indicative of trends.

For the survey, certified Class A mechanics were interviewed about their knowledge of the diagnosis and repair of emission control systems. Sixty-three mechanics were interviewed in three cities in California -- Los Angeles, San Diego and San Francisco -- with over half the interviews conducted in Los Angeles, so that geographical differences among mechanics would be apparent. Interviews were restricted to certified Class A mechanics as these credentials are required for mechanics to repair vehicles failing the emission inspection. In order to capture the diversity of mechanics' abilities, the survey sample included mechanics from dealerships, repair chains (such as Sears, K-Mart) and independent repair facilities. All mechanics interviewed had Motor Vehicle Inspection Program (MVIP) or Motor Vehicle Pollution Control (MVPC) experience. Mechanics were individually interviewed using an open ended questionnaire by representatives from J.D. Power. These interviewers were not trained mechanics, but had general familiarity with emission control systems and were briefed in detail about the performance of these systems by EEA staff. Given the limitations in knowledge and the time constraints facing the interviewers, it was not possible to probe several ambiguous statements by mechanics. Hence, some of the results appear contradictory, but reflect the survey data as collected.

Specialization seems to be widespread among most mechanics. Chain shops do little more than tune-ups on vehicles with the conventional emission control systems. Independent garages often have individual mechanics specialize in certain types of systems such as fuel injection or certain makes of cars with relatively more complex emission control systems.

Dealership mechanics obviously specialize in the vehicle types sold by the dealership, although they receive exposure to other vehicles that are traded in for resale by the dealer. However, many of the dealership mechanics did not know about system peculiarities in late model vehicles other than the ones sold by the dealership primarily because their exposure to other vehicles is limited to the older vehicles traded in by consumers.

The survey reported that mechanics appear generally satisfied with the availability of manuals. This comment must be read in the context of mechanics usually having some areas of specialization in the newer, more complex emission control systems. If the manuals are not sufficient or do not provide the needed information, mechanics will generally call the service department of a dealership or a manufacturer representative for additional information. Mechanics also appear to have some trouble understanding the certification requirements for the I/M test administered in the Los Angeles area (San Francisco and San Diego do not require a retest by the state facility) and, hence, sometimes call the ARB for information on standards for specific types of cars. Mechanics emphasize that the information in service manuals or troubleshooting charts was secondary to the primary source of information --experience. Most mechanics found that following the charts was laborious and time consuming and experience generally provides the fastest way to find a problem. Mechanics said that they used the manuals and charts on new or unfamiliar vehicles but few mechanics admit to using a trial and error method for diagnostics. All mechanics uniformly found the stickers or decals under the hood to be very useful -- especially those providing vacuum hose diagrams. Some asked that more information be provided on the sticker, e.g., spark plug gap, CO levels and carburetor settings.

Mechanics at chain shops and independents stated that meeting the cost limitation, rather than correct and complete repair of the vehicles, is the primary objectives of their work. These mechanics state that they fix only the minimum necessary for a vehicle to pass the emission test. The state imposed repair cost ceiling of $50 appears to be the prime reasons for this and with labor costs of $30-$40/hr., there is little leeway for the mechanic to spend time ensuring the vehicle is up to manufacturer specification. Dealership mechanics, on the other hand, appear to be more willing to restore the car to specifications, possibly because much of their work on emission control is done under warranty.

It became readily apparent that most mechanics are conversant with the diagnosis and repair of EGR systems and secondary air systems equipped with an air pump. Pulse air systems (available on some Japanese vehicles and the Chevette) are poorly understood, although this may reflect the fact that many mechanics may never have worked on cars equipped with such systems. Similar lack of knowledge is displayed by mechanics on "closed-loop" or feedback systems, although it is possible that the terminology may be confusing to the mechanics. Mechanics also appear unfamiliar with differences between mechanical and electronic fuel injection systems. Overall, mechanics tended to have knowledge of either mechanical or electronic fuel injection systems, but not both, reflecting the specialization in the field. Similar lack of knowledge was reported on the newly developed internal diagnostic systems (available on all 1981+ GM cars and some Ford vehicles). Some mechanics responded that feedback carburetors, electronic controls, and internal diagnostics were hard to repair, and many others provided responses that were ambiguous at best, leading EEA to believe that it is likely that those mechanics knew little about such systems. A surprising number of mechanics (75%) claimed that they inspect the catalyst, while several even claimed that they measure CO/HC readings with and without the catalyst (by physically removing the catalyst) to examine if the catalyst is actually functioning or not.

4. DESIGN OF GENERALIZED DIAGNOSTIC METHODS

Given the wide diversity in emission control systems technology, it was recognized that no generalized procedure could be expected to diagnose every component of the emission control system for every make and model available. Secondly, the development of these procedures was predicated on the assumption that the mechanic was competent on earlier (oxidation catalyst) technology and was therefore, starting from a knowledge base where it was not necessary to explain the basic operating principles of engine components such as carburetors or fuel-injection systems. EEA recognizes that many mechanics do not, for example, understand the operating principles of fuel-injection systems; the objective of the procedures developed here is not to educate such mechanics on fuel-injection systems, but to expand the knowledge of those who already understand the basic principles of such systems into the area of "closed-loop" fuel-injection systems. Thirdly, given the resource constraints of the contract, it was decided that the effort would be directed to provide diagnostics in areas in which mechanics appear to need the most help.

The first step in defining the requirements of the diagnostic procedures was to identify these emission control system malperformances that cause significant increases in emissions. It was reasoned that if a generalized procedure should capture most, if not all, the malperformances causing significant increase in emissions -- defined in this study as causing a vehicle to fail the FTP or I/M emission standards by a margin of 15 percent or greater -- such a procedure would be of greatest benefit to the CARB.

Based on results from studies conducted by ARB and EPA, it was concluded that the fuel system diagnostic needed to consider:

- The oxygen sensor
- The coolant temperature sensor
- The computer
- The computer ground
- The throttle position sensor
- The manifold pressure sensor or airflow sensor (for fuel-injected vehicles only).

Based on the mechanics survey, EEA concluded that most mechanics understood EGR systems and secondary air systems on older cars but could use some information on more recent changes to these systems, e.g., backpressure EGR and the inclusion of the switch valve in the secondary air system for "closed-loop" three-way catalysts. Mechanics were less knowledgeable in the operation of the closed-loop system and many were clearly unqualified in electronic fuel injection systems and internal diagnostics. Accordingly, EEA devoted a greater effort in providing generalized diagnostic procedures for such systems than for EGR, secondary air and open-loop fuel systems. Finally, our literature review and the mechanics survey revealed no promising methods currently available for diagnosing malperforming catalysts; EEA, therefore, has attempted to develop tests for catalysts.

In our development of the procedures, it was apparent that a preliminary description of system operating would be required since the survey results showed that many mechanics do not understand the operating principles of "closed-loop" systems. A key aspect of these systems is that the computer controls the secondary air, EGR and fuel systems and a malperformance in the fuel system (especially the closed-loop portion) often causes the computer to shut down EGR and divert secondary air to atmosphere. Thus, the different systems can malfunction in an interrelated manner.

Table S-1 outlines EEA's flowchart for the generalized diagnostic procedures. Conversations with manufacturers reveal that a pictorial description

TABLE S-1

BASIC REQUIREMENTS FOR
DIAGNOSTIC METHOD

System Description/Mechanic Orientation

- Components
- Connections
- Method of operation

Sequence of Diagnostics

(1) Secondary Air System

(2) EGR

(3) Fuel System

  (a) Performance Test

  (b) More Specialized Tests

(4) Catalyst

System Performance Test For Each System

- Methodology
- Test Description
- Tools needed

Test Response And Action For Each Test

- List of possible responses to each system performance test
- Reasons for the response
- Recommendation for repair or alternative action

of the operation of closed-loop systems is recommended. Although such a description is not included in this report, many manufacturers have provided such materials for seminars --for example, both GM and Bosch provide a pictorial representation of the operating principles of "closed-loop" systems. Such standardized representations are useful in aiding the mechanics' understanding of the system.

The procedures developed by EEA are widely applicable and require no special tools other than the ones required by BAR for licensed Class A mechanics. The procedures are required to be performed in the <u>sequential order of their</u> appearance. The generalized procedures assume that the mechanic is familiar with the conventional (oxidation catalyst) emission control technology and has an understanding of the operating principles of the overall system. In all cases, tests are required to be performed on warmed-up cars.

The procedures developed under Phase I were refined and validated in Phase II of the study. In this executive summary, the final recommendations for test procedures are provided in the following section.

S.2 PHASE II: VALIDATION

1. OVERVIEW

Under Phase I of this contract effort, EEA developed generalized diagnostic procedures for emission control system malfunctions in three-way catalyst equipped cars. The diagnostic procedures are designed to accommodate a wide variety of makes and models, and are relatively simple to use. When the contract was first initiated, there was concern that the procedures developed would be difficult to understand, especially for a field mechanic with no advanced training. Therefore, the initial plan required that 10 cars which had intentional disablements be tested by 10 mechanics with a relatively broad spectrum of experience levels. The validation would, therefore, have tested the ability of field mechanics to understand and utilize the diagnostic procedure over a small sample of cars. At the end of Phase I, it was found that the procedures were relatively simple to understand, and the focus of the validation shifted to testing the applicability of the diagnostic procedures to a wide variety of cars.

Accordingly, the revised test plan called for utilizing only two mechanics (to provide a cross-check) but testing 60 vehicles representing a wide variety of emission control system designs. All cars tested had have closed-loop emission control systems, but differed considerably in their secondary air, EGR and fuel systems. Although some tests were recommended for the catalyst system, catalyst testing was performed separately from the validation study. All tests involved rented vehicles and were, therefore, tests on relatively new cars. Tests were conducted in the Washington, D.C. area and the two mechanics participating in this study were recruited for their above average skills and training -- both mechanics have had some college and one taught small engine repair at a technical school. The mechanics were chosen so that they could provide insights on how best to improve the diagnostic procedure, and were, therefore, not necessarily representative of the average mechanic in their understanding of the procedure. Since the procedures are straightforward, EEA anticipates no difficulty for any certified mechanic to understand the recommended procedures.

2. TEST PLAN

The validation included a training seminar conducted by the lead technical project manager, and the technical project consultant prior to the initiation of vehicle testing. It was found that both mechanics participating in the study -- Mr. Tom Berlin and Mr. Tim Bell -- had only a vague idea of the principles of operation of closed-loop systems. A portion of the training program was, therefore, devoted to explaining the general principles of closed-loop systems and their various distinguishing features. A second area where a lack of understanding was found was in the differences between single-bed and dual-bed catalysts. The differences between the two types of catalysts were explained along with the requirements for secondary air with each type of catalyst. Four cars -- carburetted, throttle-body fuel injected, mechanically fuel injected and multi-point electronic fuel-injected --were rented for the purposes of training and the entire procedure was demonstrated on each of the four cars. The training period of about four hours was the only training provided for this validation study.

During the validation, EEA had planned to evaluate the procedures over 60 cars. However, the high rental costs and the high level of technical intervention required by the lead technical project staff resulted in the validation being conducted with only 52 cars. Although ideally, all 52 cars would be different makes and models, some cars that were procured had inoperative or defective emission controls in an "as received" condition. Since the validation procedure did not allow for replacement of parts, these vehicles could not be repaired although the mechanics were able to identify the problems (in most cases) with the vehicles in question. In order to provide mechanics with more experience on such cars, correctly performing vehicles of the same type were procured and the usual method of validation, as described below, performed.

The validation procedure was as follows: each car to be tested was procured from a car rental company (as a result, the cars were mostly relatively new vehicles). The car was ferried to Mr. Berlin, who served as the control mechanic. He inspected the car and performed the entire diagnostic procedure by selectively disabling components in the fuel system, EGR and secondary air systems. The effect of each disablement on HC/CO emissions, RPM and any internal diagnostic lights (if applicable) was noted along with a comment on the correctness of the diagnostics developed by EEA. He then introduced one or more malperformances in the emission control system as determined by the overall project requirements. The car with the intentional malperformance(s) was sent to the second mechanic, Mr. Bell, who used the recommended procedures to locate the malperformance, and noted the vehicle behavior (RPM/HC/CO) during the various tests conducted. Once he completed diagnosis, he verified its correctness by questioning Mr. Berlin. He then introduced one or more malperformances -- after restoring the original one -- and then returned the car to Mr. Berlin. Mr. Berlin then repeated the diagnostic procedure to identify the malperformances introduced by Mr. Bell, and then returned the car to "as received" condition prior to its return to the renting location. This formed the test plan followed for the validation.

3. VEHICLES/MALPERFORMANCES TESTED

In order to provide a good representation of the different types of emission control systems used in the fleet, as well as a wide spectrum of manufacturers, the following types of emission control technology were tested:

- Carburetted, single-bed catalyst
- Carburetted, dual-bed catalyst
- Throttle-body fuel injected, single/dual-bed catalyst
- Mechanically fuel-injected
- Electronic, multi-point fuel injected

Under Phase I, the following component failures were identified as having potentially significant impact on emissions:

- Oxygen sensor (OXS)
- Coolant temperature sensor (CTS)
- Throttle position sensor (TPS)
- Electronic Control unit, or computer
- Primary air/fuel ratio controller
  - mixture control solenoid for carburetors (MCS)
  - frequency valves for mechanically fuel injected systems
  - vacuum or air flow sensor for electronic fuel-injection systems
- Air temperature sensor (in a few vehicles)
- EGR vacuum control
- Secondary air diverter valves

Although the original intent was to test a large fraction of vehicles with <u>more</u> than one of the above components disabled, it was found that most vehicles would not run (or run so poorly that it was not driveable) with several disablements. In the interest of safety, most vehicles were tested with usually one, or at most, two disablements. The type of disablements tested by emission control technology type and the number of vehicles tested is detailed in Table S-2.

4. REVISED DIAGNOSTIC PROCEDURES

The vehicles tested during the validation provided a number of examples where the diagnostic procedures needed to be modified or revised. We have summarized the problems encountered during validation in Table S-3.

TABLE S-2

MIX OF CARS/MALPERFORMANCES USED IN VALIDATION

		Sensors							
Type	Sample Size	Ox.	Coolant Temp.	Throttle Position	Airflow/ Manifold Vac.	Computer	EGR	Secondary Air	Mixture Control Solenoid
Closed-Loop Carburetor Single-Bed Catalyst	8	X	X	X	-	X	X	X	X
Closed-Loop Carburetor Dual-Bed Catalyst	16	X	X	X	-	X	X	X	X
Throttle-Body Fuel Injection*	14	X	X	X	X	N/A	X	X	N/A
Mechanical Fuel Injection	6	X	N/A	-	-	X	N/A	N/A	X
Electronic Port Fuel Injection*	8	X	X	X	X	N/A	X	N/A	N/A

*Some malperformances caused vehicle to be undriveable. In such cases, other alternatives were used.

TABLE S-3

SUMMARY OF PROBLEMS ENCOUNTERED

Vehicle	Problem	Cause	Action Recommended
Isuzu I-Mark	Difficult to check EGR and diverter valve	No access to either valve	Use vacuum check only for EGR. Use hand-held mirror for inspecting diverter valve.
Mitsubishi Tredia	No response to closed-loop check	Unable to determine	Check if any special procedure is required for turning on closed-loop.
Buick Regal	EGR not functioning during test at idle	Transmission must be in "drive" to turn EGR on	Modify diagnostic procedure to include check with transmission in drive
Chrysler New Yorker (2.6 Litre)	One piece TPS difficult to check	Access to connection limited	--
Nissan Sentra	"Spike" response when oxygen sensor harness is grounded	Computer probably recognizes disconnect of oxygen sensor	Modify diagnostic procedure to allow for "spike" response
All Chrysler 2.2 litre	No response to closed-loop check	Microswitch on throttle turns off closed-loop at idle	Modify diagnostic to specify performing closed-loop check with throttle opened using accelerator

TABLE S-3 (cont'd)

Vehicle	Problem	Cause	Action Recommended
All closed-loop carburetted Toyotas	No response to closed-loop check at idle or in-gear	Unique air-bleed system that uses closed-loop only at load	Diagnostic inapplicable, must use manual.
Fuel-injected Ford (1984 and later)	System does not respond to repair	Computer memory must be reset after repair	Disconnect battery terminal and reconnect to erase memory
Ford LTD	No response to closed-loop check at idle	Vehicle must be in-gear for closed-loop turn on	As for Buick Regal
Renault Alliance	No response to closed-loop check at times	Intake air must be above 60°F for closed-loop turn on	Modify diagnostic procedure to ensure fully warmed up engine with "stove" in place
Nissan Maxima/ Toyota Starlet	Mechanic unable to identify problems with airflow sensor or manifold pressure sensor	No procedure in recommended diagnostics	Include check of these components in this diagnostic procedure
Electronically fuel-injected systems	Difficult to trace source of problem	No physical check possible of sensors	If sensor failure is suspected, either replace or check with service manual

Based on these data, and the mechanics' comments on the test procedure, the following revisions to the recommended procedures were made:

- Secondary Air System - No major revisions were required as the diagnostics proved adequate. However, some minor wording changes that clarify when engine should be running or off is included to prevent any confusion. EEA also recommends that mechanics be instructed about the differences between a single-bed and a dual-bed catalyst system in their secondary system operation.
- EGR Systems - We have added the caution that in many cars, EGR is turned on only with vehicle in gear. Other minor wording changes to clarify engine operation during each check are included.
- Closed-Loop System - Mechanics have been cautioned about the existence of switches at the throttle that turn on the closed-loop, and are advised to try with the car in gear or on a dynamometer (if available). These cautions are to prevent closed-loop clamps at idle from defeating the diagnostic. Wording on the diagnostic charts have been modified so that the sequence of events - in case of no response from the closed-loop - becomes evident.
- Feedback Carburetors - This diagnostic chart was one of the most successful in its original form, and the only minor correction is the requirement to repeat the test with vehicle in gear or on a dynamometer, as described in the closed-loop system check.
- Bosch K-Jetronic System - Another diagnostic chart that was successful in its original form. However, as recommended by mechanics, the system behavior and the check for the thermo-sensor (used in warmup) is now added to the diagnostics.
- Electronically Fuel-Injected Systems - As derived from the validation procedure, checks for the manifold pressure sensor/airflow sensor and vacuum connectors to the manifold pressure sensor are included. Additional cautions are introduced to try check with car in gear, and to clear the "keep-alive" memory (whenever applicable) after repairs are made. EEA recognizes the difficulty with identifying the various sensors and the difficulty in checking them when harness connectors are complex, but no meaningful general system to decode the wiring diagram is possible.

5. DIAGNOSTIC PROCEDURES

The revised recommended procedures are fully described in Tables S-4 through S-9. The revisions will result in diagnostic applicable to most makes and models, but not to carburetted Toyotas and Hondas. There are also some obvious limitations in the generalized procedures as applied to all electronic fuel injection, as at some stage a detailed wiring diagram may be required.

The diagnostics requires that the systems must be checked in the following sequence:

- Secondary air system
- EGR system
- Fuel system
- Catalyst

6. CATALYST DIAGNOSTICS

Although the diagnostics of secondary air, EGR and the fuel system were developed under Phase I of this study, it was not possible to develop adequate diagnostics for catalysts. However, based on theoretical principles, we developed two checks that could be potentially useful in diagnosing failed catalysts. They are:

- Disconnecting a spark plug and checking (with engine running at fast idle) the tailpipe HC emissions. We had postulated, based on a small sample, that a good catalyst could have tailpipe emissions of less than 1,000 ppm HC whereas a bad catalyst could exceed 1,500 ppm HC, while tailpipe readings in between 1,000 and 1,500 ppm would signify a partially deteriorated catalyst.
- Removing the oxygen sensor and checking HC emissions before and after the catalyst, by inserting the emissions probe through the oxygen sensor part. This test was to be conducted at fast idle.

TABLE S-4

SECONDARY AIR SYSTEMS WITH AIR PUMP

Ensure air pump is connected and belts are tight. Check for any obviously cracked or broken hoses before starting engine.

Performance Test

(1) Dual-Bed Catalyst Systems - After car is warmed up, check for air supply to catalyst by removing the hose connecting diverter valve to catalyst when engine is running.

- If Air Supply to Catalyst - System OK
- If no Air Supply to Catalyst - Check for air and air supply from pump outlet to exhaust manifold

Caution - If air is being diverted to atmosphere or air cleaner, it may be because of "closed-loop" problems (see closed-loop check).

Test Response	Probable Cause	Action
No Air from Pump	Pump Failure Loose Drive belt Leaks in hose	Replace Pump. Tighten. Replace hose or hose fitting.
Air supply to exhaust manifold	Vacuum present at switch valve	Check vacuum hose routings. Check computer.*
	Switch valve inoperative	Replace valve.
Air dumped to air cleaner/atmosphere	Diverter valve inoperative	Check computer.* Replace diverter valve.
Heat damage to hoses and air pump	Check valve inoperative	Replace check valve.
Backfire during deceleration	Diverter valve inoperative	Replace diverter valve.

*See "closed-loop" system performance check.

TABLE S-4

SECONDARY AIR SYSTEMS WITH AIR PUMP
(Continued)

(2) Single-Bed Catalyst System - After car is warmed up, check for air supply to air cleaner or atmosphere with engine running.

Caution - If air pump is supplying air to exhaust manifold, it may be because of "closed-loop" problems (see closed-loop check)

Test Response	Probable Cause	Action
Air supply to exhaust manifold	Vacuum present at switch valve	Check vacuum hose routings. Check temperature sensor.*
No air from pump	Pump failure Loose drive belt Leaks in the hose or hose fittings	Replace pump. Tighten belts. Replace hose or hose fittings.
Heat damage to hoses and/or air pump	Check valve inoperative	Replace check valve.
Backfire during deceleration	Diverter valve inoperative	Replace diverter valve.

PULSE AIR SYSTEM

Performance Test - With engine running, check for hissing noise near pulse air valve. With engine off, see if rubber hose or air valve exhibits heat damage. Apply a vacuum to the rubber hose connecting pulse air valve to air cleaner. Valve should hold vacuum for two seconds. Replace valve if there are signs of heat damage or it does not hold vacuum for two seconds.

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*See closed-loop system check.

TABLE S-5

DIAGNOSIS OF EGR SYSTEMS
(Backpressure and Ported Vacuum System)

System Performance Check: With engine off, place finger under EGR valve and push on diaphragm. EGR valve should move freely from open to close (or replace EGR valve). With vehicle in "Park" or "Neutral" and engine running, open throttle to increase engine rpm to 2000. EGR diaphragm should move up (valve open). With backpressure EGR, exhaust must be blocked partially to create enought backpressure for EGR to open. Close throttle on engine and EGR valve should close.

Caution - In some cars, EGR vacuum is turned on only when car is in gear.

Test Response	Probable Cause	Action
EGR valve does not open on system check	Vacuum hoses improperly connected or leaking	Check and replace hose.
	Defective EGR valve	Connect external vacuum to EGR valve. With engine at fast idle apply vacuum to valve. If valve does not open, replace.
Valve does not open on system check, opens with external vacuum	Place car in gear with brake on. Check for EGR valve movement	
	Defective thermal vacuum switch (TVS)*	Disconnect TVS and bypass it. If EGR valve opens, replace TVS.
	Defective control plugges vacuum passage	Check EGR vacuum at carburetor of manifold. Clean vacuum passages.

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*In some cars, the EGR vacuum is controlled by an electrical solenoid that is turned on by the computer. If solenoid is inoperative, replace or else check computer.

TABLE S-5

DIAGNOSIS OF EGR SYSTEMS
(Backpressure and Ported Vacuum System)
(Continued)

Test Response	Probable Cause	Action
EGR valve open at idle	Vacuum control defective	Disconnect vacuum hose from valve. If valve closes, check carburetor for sticking throttle. If valve opens, replace EGR valve.
Engine rough at idle with EGR valve closed	High EGR leakage with valve closed	Remove EGR valve and inspect to ensure poppet is seated. Clean deposits, if necessary or replace.

TABLE S-6

CLOSED-LOOP SYSTEM PERFORMANCE CHECK AND OXYGEN SENSOR CHECK
Common For All Closed-Loop Cars
Except Carburetted Toyota and Honda Cars

1. Disconnect at harness connection at oxygen sensor.

2. Connect voltmeter (use high-impedance voltmeter) to oxygen sensor. Start car and warm-up at fast idle.

3. Touch oxygen sensor harness lead with one finger. Using the other hand, touch battery positive (+) terminal (engine in fast idle).

4. If system is okay:

   - Engine speed will decrease when touching battery + terminal. Speed decrease will be audible, in excess of 100 rpm.

   - Engine speed will increase if the harness lead is grounded (-). Speed increase will be audible, in excess of 100 rpm.

   Caution - In many cars, closed-loop is turned on with a throttle switch (Chrysler cars) or in gear (Mitsubishi, Renault). If there is no response, try test with foot on brake or clutch, and vehicle in gear. Try test on dynamometer with vehicle in gear, if possible.

5. As engine speed increases and decreases voltmeter connected to oxygen sensor should read 0.5 to 1 volt when engine speed is high, 0 to 0.2 volts when engine speed is low. Disconnect air pump for dual-bed catalyst systems. If system is okay, no voltage on oxygen sensor, check CO reading with the harness lead grounded. If CO reading is higher (>2 percent), replace oxygen sensor. If CO reading is low, check for vacuum leaks, adjust idle mixture to specification and repeat test (idle mixture adjustment not applicable for EFI systems).

6. If system does not respond, go to appropriate detailed diagnostics depending on whether car has converter, Bosch CIS fuel injection of electronic fuel injection.

Note: If secondary air is being diverted to atmosphere on GM and Ford cars, this is an indicator that the closed-loop system is malfunctioning. However, no modification to the system performance check is required.

TABLE S-7

DIAGNOSTIC METHOD FOR FEEDBACK CARBURETORS

1. Connect dwell meter to carburetor solenoid.

2. Turn engine on. Carburetor solenoid should click audibly. Dwell meter should read a constant value of 18-30°.

3. Start car and warmup. Perform closed-loop system performance check. Dwell meter must read low when harness is grounded, high when finger is touching battery.

Test Response	Probable Cause	Action
No dwell meter reading	Loose connection to solenoid	Repair.
	Computer inoperative	Replace computer.
	Disconnected ground	Check ground lead and tighted.
No audible clicking (dwell okay)	Try with car in gear*	
	Carburetor solenoid inoperative	Clean solenoid, or replace.
Low dwell ($< 30^{\circ}$) with finger touching battery	Loose connection in oxygen sensor wire	Check continuity and replace.
	Coolant Temperature sensor failed (open)	Check connections to sensor. Check resistance and replace sensor if open.**
	Computer inoperative	Replace computer.
	Throttle position sensor (TPS) inoperative	Check connections to TPS. Measure resistance of TPS with throttle closed and open. Replace TPS if resistance out of specification.

*Use brake or clutch to prevent motion, or use dynamometer if available.
**Use brake or clutch to prevent motion, or use dynamometer if available.

TABLE S-7

DIAGNOSTIC METHOD FOR FEEDBACK CARBURETORS
(Continued)

Test Response	Probable Cause	Action
High dwell ($>50^{\circ}$) with oxygen sensor connector grounded	Coolant Temperature sensor failed (short)	Check connections. Check sensor resistance and replace if shorted.
	Computer inoperative	Replace computer.

TABLE S-8

DIAGNOSTIC METHOD FOR BOSCH K-JETRONIC FUEL SYSTEM

1. Connect dwell meter (high-impedance)* to frequency valve input or to test socket, if available.
2. Turn ignition on. Frequency valve must click audibly. Dwell (on 4-cylinder scale) must be about 60°.
3. Perform closed-loop system performance test. Dwell meter must go from 90° when harness is grounded to less than 50° when finger is touching battery.
4. If system performance check fails and engine is running lean (i.e., rough idle) check for vacuum leaks or clogged injectors.

Test Response	Probable Cause	Action
No audible clicking (dwell meter reads 60°)	Frequency valve inoperative	Replace frequency valve.
No dwell meter reading	Frequency valve failed	Check resistance. If lower than 3 ohms, replace.
	No connection between computer valve	Check harness for continuity.
	Bad computer	Replace computer.
	Disconnected ground	Check ground lead and tighten.
System performance check fails (no change in speed)	Bad connection in wiring harness for oxygen sensor connection	Check continuity, replace wire or connector
	Computer inoperative	Replace computer.
	Air flow sensor damaged or incorrectly ste	Set idle adjustment in air flow sensor, repair if necessary.
System performance check OK, CO high	Memo-Sensor for cold start warmup fails	Check and replace as necessary.

*Caution: Low impedance dwell meters may not provide any response.

TABLE S-9

DIAGNOSTIC METHOD FOR ELECTRONICALLY FUEL-INJECTED SYSTEMS

1. Disconnect air pump by removing hose connection (if applicable). Insert CO probe in tailpipe. Proceed as in system performance test. Try with car in gear if system performance check fails in neutral.
2. If engine is running rough at idle, check for vacuum leaks.
3. Ground sensor harness. Engine should speed up from fast idle.

Test Response	Probable Cause	Action
No engine response CO very high (3 percent)	Manifold Pressure Sensor (MPS) or Air Flow Sensor (AFS)	Check if vacuum hose is connected to MPS. Check for open or short in MPS or AFS.
No engine response CO high	Coolant Temperature Sensor (CTS)	Check if sensor is shorted or open at harness. Replace if necessary.
	Throttle Position Sensor (TPS)	Check movement of sensor. Check if sensor is shorted or open and replace.
	Harness	Check connections to CTS, TPS, and injectors. Repair as necessary.
	Computer Air Flow Sensor (if applicable)	Check for Idle adjustment.

TABLE S-9

DIAGNOSTIC METHOD FOR ELECTRONICALLY FUEL-INJECTED SYSTEMS (Continued)

Test Response	Probable Cause	Action
No engine response CO low	Fuel pressure	Check if fuel pressure regulator is damaged. Check if fuel pressure from pump is at specification.
	Injectors	Check injector spray. Clean or replace as necessary.
	Repeat checks for high CO case.	
Engine responds CO high	Fuel Pressure	As above.
	Injectors	As above.

At the request of the ARB, we added a third check, which was to measure the temperature of the exhaust pipe before and after the catalyst.

Due to funding limitations, only a small number of cars could be tested. A major problem encountered was in obtaining catalysts that were definitely damaged or poisoned. We obtained used catalysts that, in many instances, appeared partially clogged probably as a result of poisoning. Additionally, these catalysts were doused with leaded gasoline and lit off, to ensure that thermal damage and lead poisoning occurred. To prevent any unburnt remaining gasoline from giving spurious emission readings, vehicles were driven with the 'bad' catalysts until idle emissions were relatively stable and showed no further signs of decrease. These catalysts were contrasted with the 'as received' catalysts on the rented cars to provide a measure of emission characteristics of 'good' vs. 'bad' catalysts. All of the vehicles tested were relatively new, except for the Volvo 244, which had approximately 50,000 miles on the odometer.

A total of 12 cars were tested, and included a wide variety of vehicles -- European, Japanese and domestic - featuring all types of fuel systems. Due to difficulty in obtaining dual-bed catalysts that were malfunctioning or disabled, we had to limit the number of dual-bed vehicles tested to two. However, the method recommended for checking catalysts makes it immaterial if the catalyst is single-bed or dual-bed.

As a precondition to all catalyst checks, it is required that the engine emission control components not be malfunctioning. This is necessary because three-way catalysts operate only when the closed-loop system is functioning. If the exhaust gas mixture is very rich, then even a operational catalyst will be unable to oxidize the HC and CO emissions. Thus, all tests were conducted on vehicles with no additional malperformances present. A few preliminary tests revealed:

- With the engine operating properly, engine-out emissions are typically very low at idle or fast idle.
- Vehicle utilizing secondary air have engine-out and tailpipe emissions that are at the measurement threshold. Additionally, the secondary air cools the exhaust so much that temperature readings are nearly constant across the catalyst.

As a result, it was decided to test all vehicles with: 1) secondary air disconnected or diverted, whenever applicable and, 2) one spark plug disconnected to increase engine-out unburnt HC.

The first test that measured HC and CO at the tailpipe only, shows that in every case except one, HC emissions with a good catalyst were consistently below 1,000 ppm. With the 'bad' catalyst, HC emissions were usually off-scale (over 2,000 ppm).

The second test involved disconnecting the oxygen sensor, removing it from the exhaust port and placing the emission probe through the port to sample exhaust. As stated, the test was conducted at fast idle with no secondary air and one spark plug disconnected. In all cases, the 'pre-catalyst' HC emission reading was substantially higher (by a factor of at least 3) than the tailpipe reading with a good catalyst, but not with a bad catalyst. The 'pre-catalyst' emissions test with the oxygen sensor removed proved difficult to conduct in several cases because of the tight clearance between various engine components or the firewall and the oxygen sensor. Mechanics stated that an emissions probe with a tip shaped like the oxygen sensor that could be directly screwed into the port would be a great help in performing the test.

The final test involving measuring pre- and after-catalyst temperature measurements. The catalyst itself is thermally insulated and the measurements were required to be done on the exhaust pipe close to the catalyst. Since there is some rust on the pipe, the thermocouples were mounted on the exhaust pipe after rust had been ground off, exposing bare metal.

The temperature check was very successful in all cars except one. When successful, the 'good' catalyst recorded temperature increases of 75°F or more (typically 100°F). Bad catalysts, however, recorded temperature increases of 0-30°F. In one case, however, a temperature decrease was recorded for both 'good' and 'bad' catalysts. We later found that this was because the exhaust pipe to the catalyst was double-walled to conserve heat; this presents a problem for which there is no easy solution.

7. CATALYST TEST RECOMMENDATIONS

Catalyst tests can be conducted only if the rest of the emission control components are operating properly. If tests are conducted at idle, it is required to:

- Disable any secondary air to the exhaust.
- Disconnect one spark plug, and wait for about one minute until exhaust emissions are stable.
- Temperature difference defined as catalyst out-catalyst in temperature.

The following checks are then possible:

1) Measure tailpipe HC. If readings are less than 1,000 ppm, catalyst is okay. If readings are in excess of 1,500 ppm, catalyst is damaged. Catalyst is partially damaged between 1,000 and 1,500 ppm. (This test assumes that with all spark plugs connected, tailpipe HC should not exceed emission warranty requirements with a good catalyst, i.e., engine-out HC is normal.) This test is the easiest to conduct.

2) Disconnect oxygen sensor and remove. Insert emission probe through oxygen sensor port and measure 'pre-catalyst' HC. If pre-catalyst HC is greater than tailpipe HC by a factor of three or more, catalyst is good. Catalyst is bad if the pre-catalyst HC is equal to the tailpipe HC, and partially damaged if readings are between those specified for 'good' and 'bad'. This test does not require the assumption of low engine-out HC emissions, but access to the oxygen sensor port is difficult, and the test is time consuming.

3) Grind rust off exhaust pipe immediately before and after the catalyst. If temperature differential (catalyst out -catalyst in) is positive and over 75°F, catalyst is good. If below 25°F or negative, catalyst is bad, and partially damaged if between the two. This test, however, will not work if the exhaust pipe is double-walled. The test is also time consuming to conduct, and may be difficult to perform at cold ambient temperatures.

Manufacturers -- especially GM and Ford -- have expressed concerns about catalyst damage due to overheating if the vehicle is operated with one spark plug not working. Earlier tests conducted with one spark plug disconnected did not require disablement of secondary air. EEA believes that much of the manufacturers concerns should be alleviated by requiring disconnection of secondary air. (This removes the source of excess oxygen that can lead to high temperatures in the catalyst.) As an added caution, EEA suggests that the engine be operated only at no load conditions for no longer than 5 minutes with one spark plug disconnected.

S.3 ADDENDUM

DEVELOPMENT OF STANDARDIZED DIAGNOSTIC PROCEDURES FOR DIESEL ENGINE EMISSION CONTROLS

1. OVERVIEW

Increasing concern about gaseous and smoke emissions from diesel vehicles has required the California Air Resources Board (ARB) to focus on methods available for controlling in-use emissions from diesels. Diesels are currently exempt from any inspection requirements, and the development of inspection and diagnostic procedures to identify diesels with malfunctioning emission controls is of interest. In this effort, EEA has developed inspection procedures for light-duty diesel vehicles, and provided a preliminary analysis of heavy-duty diesel inspection procedures. The inspection methods are primarily for control of smoke emissions, but simultaneous reductions of hydrocarbon, particulate, and oxides of nitrogen emissions should be available as a result of implementing the recommended inspection procedures.

An engineering analysis was performed to identify the range of potential malfunctions that could result in increased gaseous and smoke emissions. The fuel injection system was found to be the most important, as it controls both the quantity of fuel injected and the timing of injection, which determines the fuel-air combustion process. The condition of the engine block and intake and exhaust systems were also found to be important. The different types of fuel injection systems were examined in detail to identify design differences that can give rise to unique malperformances and adjustments available that can be incorrectly set during maintenance or repair. Injector related malperformances were studied to verify if such malperformances could lead to high smoke. In addition, defects in the EGR system were examined at the specific request of ARB, although EGR system failures do not normally lead to high smoke.

Potentially common defects that cause large increases in smoke and/or gaseous emissions in light-duty diesels are:

- Dirty air filter
- Restricted exhaust or trap blockage
- Advanced injection timing
- Tampered fuel stop
- Leaking or sticking injectors
- Loss of compression (due to worn pistons/valves)

A similar list of malfunctions for heavy-duty diesels was also derived from engineering analysis. It was found that, while some malfunctions could cause smoke during steady-state driving modes, all malfunctions could cause smoke during a transient acceleration at full throttle.

A survey of all available data on emission tests of in-use vehicles was undertaken to identify the actual range of malperformances encountered and determine the rates of malperformance. The available data showed that high rates of emission malperformances could be associated with specific makes and models of vehicles and the common defects included: dirty air filter, maladjusted injection timing, injector malperformance and EGR system failure. (The last failure affects only NO_x emissions). A survey of current inspection programs for diesels revealed four states that have adopted such a program--Arizona, Kentucky, Oregon and New Jersey. The Arizona program is not in effect now but all states except New Jersey were found to be using inspection methods that are largely ineffective for recognizing diesels with malperforming emissions controls. New Jersey's program is restricted to buses and the inspection methods utilized may not be useful for other diesel vehicles. Data from research programs in Colorado and Oregon provided some very useful insights for designing new procedures suitable for light-duty vehicles.

2. INSPECTION PROCEDURES

In general, inspection procedures are of two types--one, where emissions are measured over a specific test cycle and the second, where engine components that are primarily responsible for controlling emissions are directly inspected. Both types of tests were designed in this effort to provide the ARB with options they can choose to implement.

For light-duty vehicles, EEA recommends that the low-speed wide-open throttle acceleration test be implemented and smoke opacity be measured using a light extinction type smokemeter. The test is formally described in Table S-10. EEA has also provided some recommended cutpoints for maximum average smoke and peak smoke during the test, but the ARB may wish to adjust the cutpoints after some samples of California diesels have been tested. The recommended procedure was validated on a small sample of cars.

The ARB has also requested that a method to inspect the EGR system be provided. This is included in Table S-3, but it must be noted that this procedure is not required for controlling smoke emissions.

EEA recommends an essentially similar test for all heavy-duty vehicles. The only other considerations are:

- An appropriate gear must be chosen so that governed speed is not reached during the 7 second acceleration test
- The smokemeter light beam must intersect the exhaust plume 5 $\pm$ 1 inch behind the plane of the exhaust pipe exit
- Opacity pass/fail cutpoints be adjusted to 25 percent for maximum average opacity and 40 percent for peak opacity.

As an option, the ARB can consider a decentralized program where components whose malfunctions that we have determined are the major causes of excessive smoke emissions are inspected. For light-duty diesels, it is recommended that the following be inspected:

TABLE S-10

INSPECTION PROCEDURE
FOR LIGHT-DUTY DIESEL

Note - Engine should be totally warmed up for test.

Tools required - one portable smoke opacity meter, light extinction type (either Celesco or Wager)

Step 1: Ensure that smoke meter is warmed up (switch on for 15 minutes before test). Attach detector to exhaust pipe so that:

- detector is perpendicular to exhaust pipe outlet
- centerline between light-source and detection device on detector is aligned to exhaust center line
- detector center line is 1 1/2 to 2 inches away from exhaust outlet

Ensure that the exhaust pipe clamp is tight. Meter unit should be placed inside vehicle.

Step 2: Vehicle can be on dynamometer or open-road. If on dynamometer, ensure that vehicle is restrained from moving forward. Start engine and, after 5 seconds, accelerate engine in neutral to maximum speed (governed speed) by pressing accelerator pedal to floor, and removing foot when engine hits governed speed. Repeat three times in quick succession. This step ensures that any accumulated particulate is blown out from exhaust.

Step 3: Set meter to read instantaneous opacity values (i.e., **not** in "peak hold"). Place vehicle in drive (for automatics) or in 2nd gear for manuals. Accelerate with gear engaged at wide-open throttle, starting from rest or 2-3 mph, for 7 1 second. Observe smoke opacity reading throughout acceleration.

TABLE S-10 (cont'd)

<u>Step 4</u>: Peak opacity reading is defined as the highest instantaneous reading observed. Maximum average opacity is defined as the value of opacity not exceeded for at least 5 seconds out of 7 seconds during the acceleration. Vehicle fails test if:

Peak reading exceeds 30 percent opacity
Maximum average reading exceeds 20 percent opacity

(These cutpoints are recommended by EEA but may be adjusted to increase or decrease inspection stringency factor.)

EGR SYSTEM CHECK

- With engine off, disconnect vacuum hose to EGR valve and connect vacuum pump. Apply vacuum to EGR valve, then release quickly. If EGR valve is OK, valve should shut audibly when vacuum is released.

- With engine running (and fully warmed up), disconnect EGR vacuum hose. Raise engine speed to hi-idle and check for presence of vacuum at hose. If no vacuum is present, electronic vacuum modulator is defective, or vacuum hose is defective.

- Intake air filter
- Injection timing
- EGR system
- Injectors
- Anti-tampering seals on fuel injection pump

The inspection methods for some of these components vary by make and model. Table S-11 provides a summary of the method and the typical time required for inspection.

For heavy-duty trucks, it is recommended that the following be inspected:

- Intake air cleaner
- Smoke-puff limiter or air-fuel ratio control
- Governed speed
- Anti-tampering seals on the fuel injection pump
- "Overhead" adjustment (for DDA and Cummins engines)

The component inspection programs can be expected to essentially achieve the same ends as the smoke inspection, i.e., repair those malfunctioning components that lead to high smoke.

3. REPAIR COSTS AND EMISSION BENEFITS

The ARB had also required an evaluation of the effect of the $50 and $100 repair cost limit for LDDV's. Based on a survey of Washington, D.C. area diesel dealership service departments, the following costs can be considered as appropriate averages:

- Inspection and replacement of dirty air filters costs about $5-$8.
- Inspection and setting of injection timing costs between $25 for GM vehicles (using the newly developed photodiode method) to $45 for a Bosch VE injection pump. Costs for Mercedes vehicles are higher ($70).

TABLE S-11

COMPONENT INSPECTION METHODS

Component	Inspection Method	Time Required
Intake air filter	Visual	2 minutes
Injection timing	Photodiode method*	20-30 minutes
	Dial indicator method**	1 hour
EGR system	Application of external vacuum	5-10 minutes (depending on accessibility)
Injectors	Visual check of spray pattern	45 minutes for 4-cylinder engines to 90 minutes for 8-cylinder engines
Anti-tampering seals on injection pumps	Visual check for presence of seal (not a functional check)	5 minutes

*Currently available for GM vehicles; may be available for other models in the near future

**Applicable to Mercedes, VW, Peugeot

- Inspection of EGR valve is a very low cost item ($5-10), but replacement of valve or controls typically costs more than $50 for Oldsmobile diesels and over a $100 for Mercedes.
- Removal and inspection of injectors for spray pattern varied from $30 for VW (4-cylinders) to $50 for GM (8-cylinders). Mercedes dealers quoted substantially higher costs ($150-$200). Replacement of the injector costs about $75-95 per injector for VW and GM cars.
- Inspection of anti-tampering seals on the injection pump is a no-cost operation. However, adjustment is typically quite expensive, in excess of $100.

EEA believes that $100 cost limit would allow a check and adjustment of air filter, injection timing, EGR and injectors on most diesel vehicles except Mercedes diesels. Replacement of any parts would be over and above the quoted costs, but these parts may be covered under the emissions warranty for vehicles with 50,000 miles or less on the odometer. Replacement of an injector (one) cost $45-60 (for VW and GM models) for the part costs and 1-hour of labor ($30-35) for a total cost of $75-95.

Based on a very small sample of vehicles that were repaired for the components malperformances listed, it is believed that the following values are representative for each repaired light-duty vehicle that fails the smoke test.

- HC - reduced by 40 to 50 percent
- Particulate - reduced by 15 to 20 percent
- NO_x - increased by 2 to 5 percent
- CO - essentially unaffected

Repair of vehicles where the EGR system has closed in the "off" position is expected to decrease NO_x by 30-35 percent with a 5 percent increase in HC and particulate emissions. Note that all the above figures are per repaired vehicle; in order to estimate the fleetwide effect, it is necessary to know the fraction of cars that would fail the inspection program and be repaired. For example, the fleetwide reduction of HC from LDDV's at a 10 percent inspection failure rate would be between 4 and 5 percent (0.1 x 0.4 = 0.04).

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16. Abstract (Limit: 200 words)

The report presents the results of a two part study. In Phase I, the contractor reviewed current manufacturer recommended diagnostic procedures for identifying vehicular emission control malfunctions on three-way catalyst equipped gasoline fueled automobiles and also surveyed diagnostic techniques used in the field. Diagnosis of malperformance was limited to the following systems: exhaust gas recirculating, secondary air, fuel, and catalyst. In Phase II, the contractor developed generalized diagnostic procedures for malfunctioning emission control systems and validated these procedures on 52 vehicles. Two mechanics alternatively disabled and repaired the vehicles using the diagnostic and repair procedures. The report also describes inspection procedures developed for the control of smoke emissions from light-duty diesel vehicles. Two types of procedures were developed, for component testing and for inspection/maintenance programs. These procedures were validated on six light-duty vehicles.

17. Document Analysis a. Descriptors

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Internal Combustion Engines

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